Experimental Studies of the Effect of Plasma Wavelength on Radiative Properties of Indium Tin Oxides Heat Mirror Films for Solar Thermal Applications [1]

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[1] Paper presented at the Fourteenth Symposium on Thermophysical Properties, June 25-30, 2000, Boulder, Colorado, U.S.A.

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Abstract

The single layer Indium Tin Oxides (ITO) heat mirror films (HMF) was deposited onto unheated glass and rigid or flexible plastic substrates by RF sputtering technique. The present studies are aimed at exploring the relation between the thermal radiative properties and plasma wavelength of ITO HMF for solar thermal application. The study reports the influence of plasma wavelength upon the thermal radiative properties of ITO HMF used as solar selective absorber. The relations between the plasma wavelength (λ_p) and radiative properties of ITO heat mirror films are given. It is shown that the optical and radiative properties can be optimized by controlling the plasma wavelength to produce efficient high quality indium tin oxides heat mirror films for solar collector absorbers.

Keywords: Thermal Radiative Properties; Heat Mirror Films; Solar Selective absorber

Introduction

Usually, the common selective absorber collects solar spectrum by multi-layer absorber films that possess a high absorptance and are deposited on a metal substrate. Since the multi-layer films are transparent in the longwave thermal radiation (λ>2.5μm) and the emissivity of metal is very low, the emissivity of these kinds of selective absorber is also very low.

The heat mirror films (HMF) are special thin films that transmit most of solar spectrum, in particular for visible region, but reflect longwave thermal radiation. There is an increasing interest for the heat mirror films in the application of solar selective surface. If such a HMF is deposited on to a cheap black plastic surface (whether rigid or flexible), then a spectral selective absorbing surface can be obtained. It differs from the common selective absorber [1]. Since there is no need for a metal substrate, the new selective absorber might be cheap than common selective absorber it depends on the price of HMF.

The high quality heat mirror films can be produced by the multilayer coating technique. However these kinds of heat mirror films are too expensive to be popularized. Single layer semiconducting transparent thin films, and indium tin oxides (ITO) in particular, are the most interested materials. We have successfully prepared the single layer ITO heat mirror films with high quality. The special characteristics of the films are: the reflectivity in the solar spectrums $\rho_s \approx 0.11$, the emissivity at room temperature $\in \approx 0.12$, the transmissivity in the visible region $\tau \approx 0.9$, the sheet-resistance $R \approx 5\Omega/$, the resistivity $\rho \approx 2.8 \times 10^{-6} \Omega \cdot$m [2].

Concerning ITO films, main studies made by various researchers are its optical and electrical properties and to make use of it for the transparent conducting and low emissivity windows. It has been reported in the literature that the optical and electrical properties of

ITO films are influenced by the deposition methods and condition, such as the O_2 concentration in the working gas, deposition rate, and substrate temperature [3-8]. Moreover the O_2 concentration is the crucial factor, which was verified by our previous work [2]. To combine the ITO HMF with rigid or flexible black substrates for producing a spectral selective absorber, the key factors are to obtain the ITO films with reflectance as high as possible in the longwave region ($\lambda>2.5\mu$m) and as low as possible in solar spectral region ($0.35<\lambda<2.5\mu$m).

Considering that the high reflectance of ITO HMF in the infrared region may take place if the ITO HMF has a low resistivity that is related with the high carries concentration. It is also know that a high carries concentration may also cause the decrease of plasma wavelength. Experimental results show that the thermal radiative properties of ITO HMF with different plasma wavelength are not alike, so it is interesting and valuable to find out the relation between the thermal radiative properties and plasma wavelength for ITO HMF and maybe it is useful for processing the ITO HMF with desirable thermal radiative properties based on taking plasma wavelength as a criterion.

In this paper we report the experimental investigations on the relation between the plasma wavelength of ITO HMF and the reflectance of ITO HMF in the solar spectrums ρ_s and the room temperature emissivity $\in$.

1. Experiments

It is difficult to measure the thickness **d**, reflectance $\boldsymbol{\rho_s}$ and transmittance **T** in the range of $0.35\leq\lambda\leq2.5\mu$m as well as reflectance $\boldsymbol{\rho_t}$ in the range of $2.5\leq\lambda\leq25\mu$m for ITO HMF deposited on the flexible plastics or black substrates. Thus in each of depositions the glass and flexible plastics were used as substrates. The ITO films deposited on glass substrates are used for measuring the film thickness, reflectance and transmittance in solar spectral region as well as the reflectance in the range of $2.5 \le \lambda \le 25\mu$m. A Si substrate was also used at the deposition of sample $A^{\#}$ and the ITO films deposited onto this Si substrate was used as specimen for AFM.

The experiment was based on our previous work [2]. The O_2 concentration in $Ar+O_2$ environment was maintained at an appropriate value. Except for deposition rate (Γ), the other deposition parameters were kept constant in each of depositions.

The ITO heat mirror films were prepared by using a conventional RF sputtering system (type *JS-350, 0-3KV, 10-13.6MHZ*) with a sintered target: 90*wt*.%In_2O_3-10*wt*.%SnO_2 and 100*mm* in diameter (sintered by ourselves at Shanghai Institute of Ceramics, Chinese Academy of Sciences). The distance between the target and the substrate, which was firmly clamped to a water-cooled substrate holder, was about 55*mm*. The target was presputtered for *18* min before each of depositions. The substrates were neither heated nor biased.

The film-thickness **d** was measured by Taylor-Hobsen talystep. The sheet-resistance ***R*** was measured by four-point probe and the conductivity σ was determined by the function $\sigma^{-1} = R\ d$. The deposition rate (Γ) was determined by Γ=d/t, where the t is sputtering time. The transmittance and reflectance in the range of $0.35 \le \lambda \le 2.5\mu$m were measured by Shimadzu spectrometer *UV-365* and the plasma wavelength λ_p can then be determined by the crosspoint of the spectral transmittance and reflectance curves. The reflectance in the range of $2.5 \le \lambda \le 25\mu$m was determined by Nicolet *Magna-IR*™ spectrometer *750*. The normal emissivity $\in_n$ was measured with a potable device [9] and the D-R method was also used for calculating the room temperature normal emissivity $\in_n$ [2].

2. Results and discussions

Table 1 shows the experimental results for ITO HMF deposited onto unheated substrates. Fig. 1 give the samples emissivity $\in$ and reflectance of solar spectral region ρ_s. It is shown from Fig. 1 that initially the $\in$ and the ρ_s decrease gradually with the decrease in the plasma wavelength till they fall to the bottom, and then rise again. Once $\in$ reaches a shoulder , it decreases steeply. However, the relation between the plasma wavelength and ρ_s is more complex as it is shown in Fig. 1.

According to the relation suggested by H. L. Hartnagel, A. L. Dawer, A. K. Jain, and C. Jagadish [3] and K. L. Chopra, S. Major, and D. K. Pandya [10], we can see that the higher the carrier concentration, the lower will be the plasma wavelength. The added carrier concentration can intensify the absorption of free electron in infrared. From the experiments, we found that the decrease in plasma wavelength of ITO HMF can cause two different effects on the films reflectance in the solar spectrums ρ_s. Firstly, the reflectance in the range $\lambda_p<\lambda<2.5\mu$m has a sharp increase resulting from the intensified free electron absorption. Secondly, the reflectance in the range $0.35<\lambda<\lambda_p$ has evidently low values, which maybe owing to the fact that the films with lower plasma wavelength have higher carrier concentration and much more carrier mobility. Fig. 1 shows the data of the reflectance ρ_s. It can be seen that ρ_s decreases with the decrease in λ_p and it will reach a minimum and then it increases again with the decrease in λ_p. For ITO HMF with high quality and good crystallinity, there is no question that to prepare ITO HMF with too little plasma wavelength is profitless.

Since all the samples were obtained with the same O_2 concentration, the sample with the plasma wavelength greater than that at the bottom, and further more, if it was deposited at a comparatively high deposition rate, is considered to be more close on stoichiometry and have bigger grain size, viz. more carrier concentration and bigger carrier mobility, and it exhibits lower emissivity. In addition, it is known that the power densities of Ar^+ ions bombing the target is increased with deposition rate. The surface state of target bombed at high power densities may be diverse from those which were bombed at a low power densities and the films obtained on the substrates can be off-critical stoichiometry. Consequently, the films with the plasma wavelength less than that at the bottom and being deposited on excessive high deposition rate have high emissivity $\in$.

From the variation of $\in$ and ρ_s with λ_p given in Fig. 1, One can see that there is a clear difference between the two bottoms where $\in$ and ρ_s reach there minimum value respectively. The important point resulting from Fig. 1 is that it is impossible for ITO HMF to possess simultaneously maximum reflectance in thermal long wavelength region and minimum reflectance in the solar spectral region.

Since the film growth is influenced by substrates on which the ITO films be deposited, and then the properties of ITO films deposited onto glass, metal and flexible plastics cannot be identical. However, Hamberg, and Granqvist reported [3] that the properties of ITO films with good crystallinity and high quality, whose crystallite size is about 50nm, are similar and the substrate conditions are not expected to be critical. From the result of AFM for sample A presented in Fig. 2, we can see spheric grain phase and the crystallite size are greater than 50nm. Taking these results into account, we think that the experimental results are valid for the ITO HMF deposited onto others substrates, even though these studies are dealt with ITO films deposited onto glass.

3. Conclusions

It is impossible for ITO HMF to possess simultaneously maximum reflectance in thermal long wavelength region and minimum reflectance in the solar spectral region.

The relation between the thermal radiative properties and the plasma wavelength for indium tin oxides heat mirror films are obtained based on experimental studies. It is shown that the plasma wavelength can be taken as a criterion to predict the thermal radiative properties of ITO HMF approximately. So the relation reported is useful for preparing of ITO HMF with desirable thermal radiative properties.

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Table 1. Data for ITO HMF deposited onto unheated substrates. The parameters listed in the table are sputtering voltages, deposition rate Γ, conductivity *σ*, plasma wavelength λ_p, transmittance in the visible range T_v, reflectance in the solar range ρ_s, and the normal emissivity $\in$.

Sample	Sputtering Voltages(V)	Γ A/min	σ $\times 10^5 \Omega \bullet m$	λ_p μm	T_v	ρ_s	$\in$(Experi-mental)	$\in$(D-R Method)
A	1800	136	2.16	1.85	>80	0.18	0.194	0.185
B	1800	137	2.19	1.82	>80	0.14	0.191	0.184
C	2000	144	2.84	1.77	>85	0.14	0.178	0.160
D	2000	140	3.45	1.61	>90	0.12	0.162	0.150
E	2200	210	3.97	1.44	>80	0.15	0.160	0.144
F	2200	215	3.38	1.42	>85	0.13	0.170	0.159
G	2600	307	2.90	1.38	>75	0.17	0.178	0.174
H	2600	307	3.51	1.36	>75	0.16	0.157	0.158

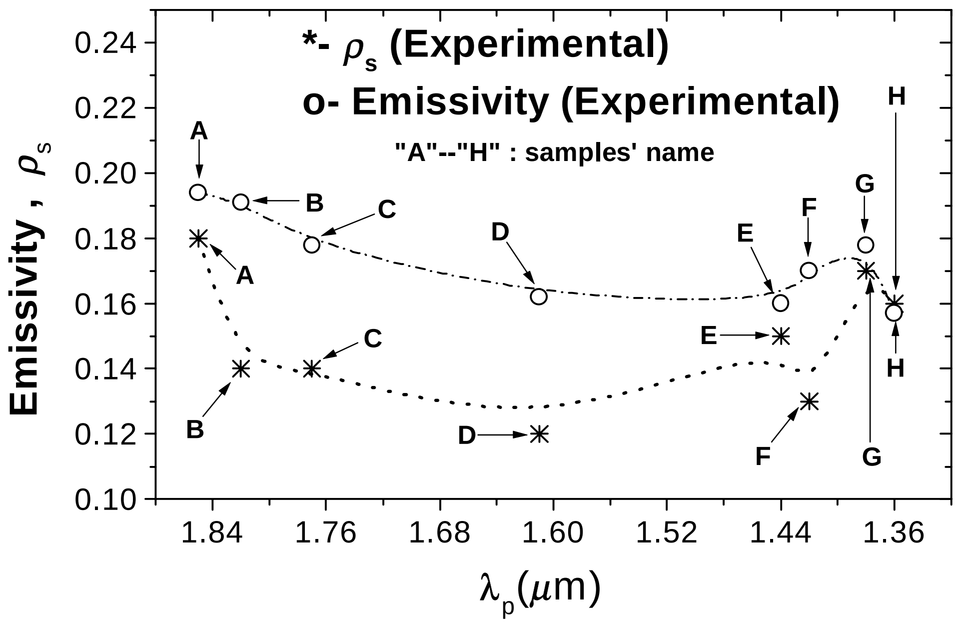

Fig. 1. The relation between ∈, ρ_s and the corresponding plasma wavelength for different ITO HMF

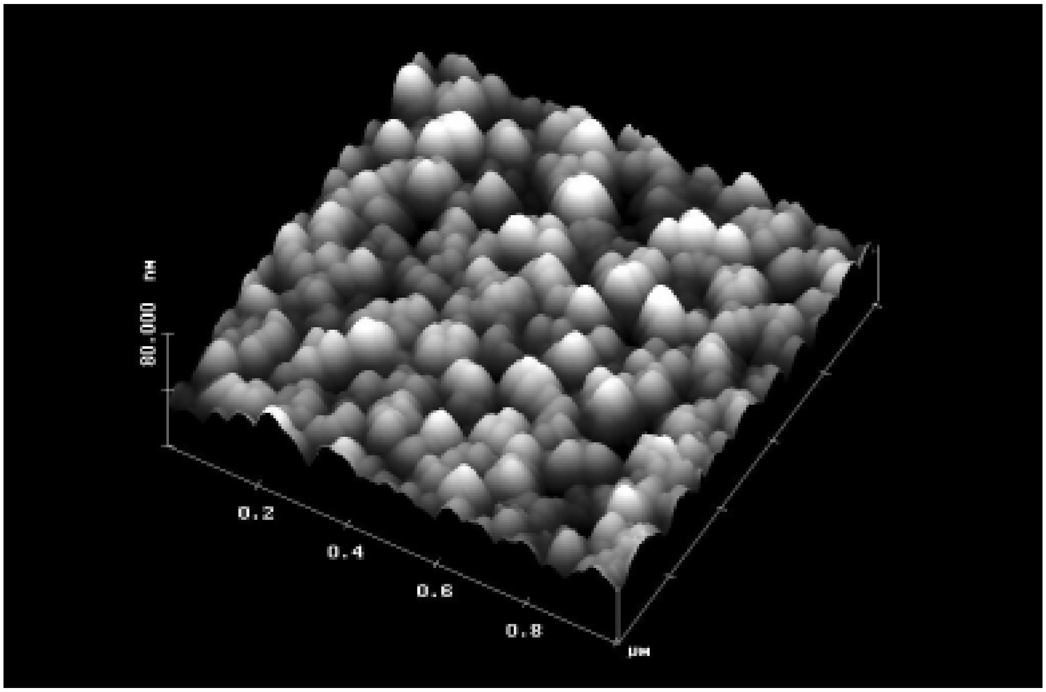

Fig. 2 The result for AFM of sample A